KATHOLIEKE UNIVERSITEIT LEUVEN

Faculty of Economics and Applied Economics

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Public Economics

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The cost effectiveness of environmental policy instruments in the presence of imperfect compliance[1]

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Abstract

We aim to integrate information, monitoring and enforcement costs into the choice of environmental policy instruments. We use a static partial equilibrium framework to study different combinations of regulatory instruments (taxes, standards…) and enforcement instruments (criminal fine, administrative fine…). The firms' compliance decisions depend on the instrument combination selected by the government. The model is used to compare the welfare effects of different instrument combinations for the textile industry in Flanders. We find that administrative, implementation, enforcement and monitoring costs are important to decide on the necessity of an environmental policy. Moreover, we show that emission taxes are not necessarily the most cost-effective instrument. This result holds even if we include industry heterogeneity. The decision of whether to pursue an environmental policy or not depends crucially on the formulation of an appropriate monitoring and enforcement policy.

Keywords: K32 Environmental Law, K42 Illegal behaviour and enforcement of law, Q28 Government policy

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January 2002

I. INTRODUCTION

When designing environmental regulation governments face many choices. One of the hardest, without a doubt, is the selection of a suitable environmental policy instrument (Bohm and Russell, 1985). One important consideration is clearly the cost effectiveness of the instruments. Traditionally[2] market-based instruments, such as emission taxes, are assumed to be more cost efficient than command-and-control (CAC) instruments since they equalise marginal abatement costs across firms and industries. The influence of monitoring and enforcement costs on the cost effectiveness of different instruments, however, is often neglected. Recently, monitoring and enforcement costs have been studied extensively in theory and often on a per instrument basis (Cohen, 2000; Heyes, 2001).

In this paper we aim to integrate information, monitoring and enforcement costs into the choice of policy instruments. Malik (1992) already showed that the decision rules for minimising enforcement costs and minimising abatement costs are different. Therefore it is not a priori certain that CAC policies are more expensive than incentive-based policies when enforcement is taken into account. Enforcement and monitoring costs are highly non-linear and depend on the legal system. Therefore we use a simple partial equilibrium model and apply it to one industrial sector (textile industry in Flanders). The simple model we use includes abatement decisions and costly monitoring and enforcement. The case study uses individual firm data to simulate the differences in abatement costs and compliance decisions between firms. For the problem of water pollution in the Flemish textile industry we compare combinations of regulatory instruments (emission taxes, emission standards and technology standards) and enforcement instruments (criminal fines, administrative fines and transaction offers). We show that the inclusion of information, monitoring and enforcement costs alters indeed the relative cost efficiency of the different instruments[3].

In the following section we describe the theoretical framework. Next we focus on the assumptions underlying the case study. In the fourth section we construct the welfare function for the different instrument combinations and discuss the results of the case study.

II. THEORETICAL FRAMEWORK

Using a static partial equilibrium framework we define the behaviour of three types of agents in the economy: firms, households and government. Each agent has a specific objective function. The environmental regulation and the associated enforcement policy determine the feasible options. The problem is one of asymmetric information since the abatement costs are known to the firms but not to the regulator.

For the regulator there are three stages in selecting an environmental policy: the rule-making stage, the implementation stage and the enforcement stage (see table 1). This succession of stages is called the regulatory chain. In the rule-making stage the regulator chooses how to tackle the pollution problem. Discussions with administrations and interest groups are held to decide on the environmental goals and on the instruments used to attain those goals. Costs linked to this stage are called rule-making costs (RC). In the implementation stage the environmental regulation is in force and in order to ensure its correct implementation some extra regulation is needed. Costs linked to this stage are abatement costs (AC) and administrative implementation costs (IC). In the enforcement stage compliance with the

[2] See, for example, Kolstad (2000).
[3] We do not consider liability rules in this paper.

regulation is ensured. A monitoring and enforcement policy is developed. Costs linked to this stage are the enforcement costs (EC). For a more detailed study of the legal and administrative process we refer to Billiet (2001).

	Description	List of Instruments
Stage 1 - **Rule making stage**	The regulator chooses the instrument to tackle pollution. Discussions with administrations and interest groups are held. Costs linked to this stage are called rule-making costs **(RC).**	Emission tax
		Emission standard Emission standard included in a license system Emission standard combined with an authorising notification duty
		Technology standard Technology standard included in a license system Technology standard combined with authorising notification duty
Stage 2 - **Implementation stage**	The environmental regulation is in force and in order to ensure its correct application some extra regulation is needed. Costs linked to this stage are abatement costs **(AC)** and administrative implementation costs **(IC)**.	Documentation duty Notification duty Inspection and maintenance duty
Stage 3 - **Enforcement stage**	The compliance with the regulation needs to be ensured. A monitoring and enforcement policy is needed. Costs linked to this stage are the enforcement costs **(EC).**	Criminal fine Administrative fine Transaction offer

Table 1

In each stage an instrument has to be selected. A list of these instruments can be found in table 1. In our model we include the following rule making instruments: an emission tax, an emission standard and a technology standard. Moreover we discuss three different versions of the emission and technology standard: firstly we look purely at the instrument itself, secondly we include the instrument in a license system and thirdly we combine the instrument with an authorising notification duty[4]. In the implementation stage the policy maker can choose among three instruments: a documentation duty[5], a

[4] In an 'authorising notification duty' system the agent has to report some information to the administration, for example, that they have installed a particular filter. This report then automatically allows ('empowers') them to, for example, continue their business.

[5] A documentation duty asks the firm to have documentation about, for example, its emissions. Nothing has to be done with the documents; firms just need to have them.

notification duty[6] and an inspection and maintenance duty[7]. Finally we also distinguish three enforcement instruments: a criminal fine, an administrative fine and a transaction offer[8].

We now describe the behaviour and objectives of the production sector, the households and the government.

1. Notation

TC_i	Total costs for firm i
AC_i	Abatement costs for firm i
$IC_{f/h/g}$	Implementation costs of firms/ households/ government
$EC_{f/h/g}$	Enforcement costs of firms/ households/ government
$RC_{f/h/g}$	Rule making costs of firms/ households/ government
p_i	Probability of detection of firm i
F_i	Fine of firm i
$viol_i$	Size of violation of firm i
sur_i	Size of firm i's overcompliance with an emission standard
$p_{es/et/ts}$	Penalty parameter associated with emission standard/ emission tax/ technology standard
E_i	Actual emissions of firm i
E_i^R	Reported emissions of firm i
E_i^A	Abated emissions of firm i
CS	Consumer surplus
PS	Producer surplus
EQ	Environmental quality

2. Production sector

In order to concentrate on the choice of instruments and the role of monitoring and enforcement we assume that the output of firms is fixed[9]. We therefore assume that firms cannot go out of business. Once the environmental regulation is implemented the firms have to make at most two decisions. First

[6] A notification duty asks the firm to communicate certain information to the administration; e.g. in order to pay taxes a firm has to notify the administration of its emissions.
[7] An inspection and maintenance duty asks firms to maintain and test its installation on a regular basis and often, by means of officially recognised expert.
[8] A transaction offer is a special kind of administrative fine used in Belgium. Administrative costs are very low for this instrument.
[9] Rousseau and Proost (2001a) analysed the general equilibrium effects of enforcement costs on the efficiency of different regulatory instruments.

firms have to decide whether to comply or not with the regulation. Next they have to decide what technology to use. Firms fix automatically the amount of emissions they emit when they decide about abatement. In the case of an emission tax, the firm also decides how many emissions they report to the administration. We successively discuss three different rule-making instruments: emission standard, emission tax and technology standard.

2.1 Emission standard

Firm *i* minimises the expected costs associated with the regulation in force. These costs include abatement costs (AC_i), rule-making costs (RC_f), administrative implementation costs (IC_f), expected enforcement costs ($E(EC_f)$) and the expected sanction ($p_i.F_i$). Some of these costs are identical for all firms and are marked with the index *f*.

Formally the firm *i* faces the following optimisation problem[10]:

$$\begin{aligned} \min_{AC_i} TC_i = AC_i + p_i F_i + RC_f + OC_f + E(EC_f) \\ s.t.\quad & E_i - \overline{E} - viol_i + sur_i = 0 \\ & p_i F_i = p_i \rho_{es}\, viol_i \\ & viol_i . sur_i \geq 0 \\ & viol_i \geq 0 \\ & sur_i \geq 0 \end{aligned} \tag{1}$$

The firm emits E_i and is subject to an emission standard $\overline{E}$. We have written this constraint as an equality in order to define slack variables. The variable sur_i will be positive in case of overcompliance. The firm itself does not benefit from this extra emission reduction but through the environmental quality improvement society does. The other variable $viol_i$ indicates if and by how much the firm violates the regulation.

When the firm is violating the environmental policy it faces an expected sanction p_iF_i where p_i is the inspection frequency and F_i is the fine. This fine depends on the size of the violation and the penalty parameter ρ_{es}. In section II.4 we look further into the assumptions underlying the monitoring and enforcement policy.

The rule-making, implementation and expected enforcement costs are identical for all firms. These costs include, among others, the costs of the firms' extra administration. Managers need to be informed about their legal obligations and the implications for their company. They may need to apply for a license. Moreover they need to collect information about the technological possibilities to comply with the standard. Some employees may need training. Measurement of emissions is necessary to evaluate the compliance status. An example of enforcement costs for firms are the costs of having to follow up the inspection and to perform a second test if necessary. A detailed identification and estimation of these costs is part of the empirical exercise and will be discussed later.

[10] We assume that firms are risk neutral. This is no innocent assumption when it comes to enforcement.

2.2 Emission tax

For an emission tax t the firm's problem can be represented as follows:

$$\min_{AC_i;E_i^R} TC_i = AC_i + t\, E_i^R + p_i F_i + RC_f + OC_f + E(EC_f)$$
$$s.t. \quad p_i F_i = p_i\, p_{et}\, viol_i\, t \tag{2}$$
$$= p_i p_{et} \left(E_i - E_i^R\right) t$$

Every year firms that are subject to an emission tax, report a certain amount of emissions E_i^R to the government. They pay taxes on these reported emissions. However, if a firm reports less than the actual amount of emissions, it is in violation and faces a penalty. We define the variable $viol_i$ as the difference between actual and reported emissions. This variable is never negative if the firm behaves rationally. Enforcement is discussed more thoroughly in section II.4

In analogy to the emission standard the rule-making, implementation and expected enforcement costs are identical for all firms. Firms now not only face information costs but also the costs for the yearly tax report. Data must be collected and reported. Calculations must be made. Moreover, the firm also has to perform measurements to know its actual emissions.

2.3 Technology standard

A technology standard forces the firm to use a particular abatement technology or production process. The firm's choice space is therefore limited. Either they comply with regulations and install the technology or they are in violation. Abatement costs are fixed for one company but can differ between firms. We allow for firm heterogeneity.

The firm's objective function is:

$$\min_{viol_i} TC_i = \min_{viol_i}\left(AC_i + RC_f + OC_f + E(EC_f);\, p_i F_i + RC_f + OC_f + E(EC_f)\right)$$
$$s.t. \quad p_i F_i = p_i\, p_{ts}\, \overline{AC_i}\, viol_i \tag{3}$$
$$viol_i \in \{0,1\}$$

The standard fixes one particular technology for each firm. The implementation of this technology can lead to different costs for each firm. Each firm has two options: either it complies with the standard and installs the technology at cost $\overline{AC_i}$ (and $viol_i$ is zero) or it does not install the technology and incurs no costs (and $viol_i$ is one). Notice that the $viol_i$ is a binary variable and not expressed in emission units.

Again rule-making, implementation and expected enforcement costs are identical for all firms. Cost for information acquisition are limited in size since the regulation already indicates which technology must be used. There is no need to know alternatives or even actual emissions.

3. Households

The households are treated as a more or less passive agent. We assume that households maximise utility:

$$\max \mathsf{U} = \max\left(CS - RC_h - OC_h - E(EC_h)\right) \tag{4}$$

We assume that consumer prices are determined on the world market. Therefore local producers and consumers do not influence prices. Consequently the consumer surplus will remain constant in our model.

Rule-making costs for households can include the possibility to object to a permit request. Administrative implementation costs result from investments in lobbying and information acquisition. Expected enforcement costs result from complaining to or warning the appropriate authorities. All these costs are considered as fixed but they vary with the instrument selected by the government.

4. Government

Government maximises social welfare *(*SW) and this is expressed as follows:

$$\max SW = \max\begin{pmatrix} PS + CS + EQ - RC_f - OC_f - E(EC_f) - RC_h - OC_h - E(EC_h) \\ +MCPF\sum_i \left(t\,E_i^R + p_i F_i - RC_g - OC_g - E(EC_g) \right) \end{pmatrix} \tag{5}$$

Social welfare comprises producer *(PS)* and consumer *(CS)* surplus, environmental quality *(EQ)*, regulation costs for firms and households and the governmental budgetary surplus corrected with the marginal cost of public funds *(MCPF)*.

In the global welfare function we include all rule-making, implementation and enforcement costs associated with a particular set of instruments but also subtract environmental benefits. Environmental benefits are subtracted to allow us to deal with the indivisibilities of the abatement costs that make comparisons across instruments more difficult (Oates et al., 1989).

Rule-making costs for the government result from meetings within the administration and with interest groups and experts. Governmental operating costs have to do with, for instance, distributing regulatory information through official publication of laws and statutes. Enforcement costs include inspection and prosecution costs.

5. Monitoring and enforcement

The monitoring and enforcement policy is modelled in a simple way and is similar but not identical to the one used by Harford (1978) and Malik (1992).

The probability of inspection is modelled in the following way:

$$p_i = \overline{p} + a\ viol_i \qquad with\ 0 \le a \le 1 \tag{6}$$

Every firm, whether it is violating the environmental regulation or not, will be inspected with a certain fixed probability $\overline{p}$. A violator, however, faces an extra possibility of being inspected. This probability $\left(a\ viol_i\right)$ is proportional to the level of violation. This does not imply that the agency knows the level of violation or even which firms are in violation. It simply represents the practice that every complaint is followed up by the environmental inspection agency. The neighbouring community, environmental pressure groups or civil servants can issue complaints when they notice something suspicious. We assume that complaints are highly correlated with the degree of violation.

We assume that every violation that is detected leads to a sanction for the violator. The three types of sanctions we use are a function of the degree of violation. We recapitulate:

$$F_i = p_{et}\, t \left(E_i - E_i^R\right) \qquad \textit{for an emission tax}$$
$$F_i = p_{es} \left(E_i - \overline{E}\right) \qquad \textit{for an emission standard} \tag{7}$$
$$F_i = p_{ts}\, \overline{AC}_i \qquad \textit{for a technology standard}$$

Finally we assume that firms, households and government know the relation between the level of violation, the probability of inspection and the sanction.

For this specification of the monitoring and enforcement policy we can analyse the decision of the firm. We describe the firms' decision rules that determine whether firms comply with the regulation or not. They also indicate which abatement technologies firms install. The rules differ for the different instruments.

5.1 Emission tax

The first-order condition that determine how much emissions (E_i^R) a firm will report is:

$$\begin{aligned} E_i^R &= \max\left(\left(\frac{\overline{p}\, t\, p - t}{2\, a\, t\, p} + 1\right).\left(E_i^O - E_i^A\right);\left(E_i^O - E_i^A\right)\right) \\ &= \max\left(B.\left(E_i^O - E_i^A\right);\left(E_i^O - E_i^A\right)\right) \end{aligned} \tag{8}$$

with E_i^O equal to the firm's initial emissions before abatement technology has been installed and E_i^A equal to the amount of emissions reduced by abatement. The difference $E_i^O - E_i^A$ is therefore equal to the actual emissions of firm *i*.

Reported emissions are equal to a fraction *B* of the firm's actual emissions as long as the fraction B is smaller than one. This fraction depends on the tax rate and the enforcement parameters. Notice that *B* is not firm specific. All firms will report the same fraction of their actual emissions. Firms will never report more than there actual emissions.

Next firms have to decide which technologies they want to install. A firm will invest in a particular abatement technology if the investment costs AC_i fulfil the following condition:

$$AC_i \leq \left[t\, B + \left(a\,(1-B) + p\right) t\, p\,(1-B)\right] E_i^A \tag{9}$$

Firms will invest in abatement if the costs of doing so are smaller than the corresponding decrease in taxes paid and expected fine.

5.2 Emission standard

When an emission standard is in force, the firm will decide to use a particular abatement technology if the investment costs fulfil the following condition:

$$\begin{aligned} AC_i \leq & \left(a\left(\frac{\max\left(E_i^O - \overline{E};0\right)}{E_i^O}\right) + \overline{p}\right).p.\max\left(E_i^O - \overline{E};0\right) \\ & - \left(a\left(\frac{\max(E_i^O - E_i^A - \overline{E};0)}{E_i^O - E_i^A}\right) + \overline{p}\right).p.\max\left(E_i^O - E_i^A - \overline{E};0\right) \end{aligned} \tag{10}$$

It will be optimal to invest in abatement if the reduction in expected fines exceeds investment costs. Once the abatement decision is taken, actual emissions are determined and also the degree of firm violation. Notice that due to the indivisibilities in the abatement cost function, firms can overcomply with the regulation. The extra emission reductions benefit society but not the firms.

5.3 Technology standard

For a technology standard the compliance decision is simple. A particular technology will be implemented if costs fulfil the following condition:

$$AC_i \leq (\overline{p}+a)p\,\overline{AC_i} \tag{11}$$

A firm will comply with the technology standard if it costs less than the expected fine. This expression will lead to a corner solution[11] for the firm.

III. EMPIRICAL ILLUSTRATION

1. Benchmark and description

In order to illustrate our theoretical model we decided to focus on the Flemish textile industry. More specifically we concentrate on the water pollution caused by textile improvement and carpet production. These two subsectors are after all responsible for most of the water pollution in the sector. Several sector studies (PRESTI, 1994-1997; Jacobs et al., 1998; Centexbel, 1996 and OVAM, 1996) provide us with useful information. For reasons of tractability we limit our study to water pollution caused by BOD[12] emissions and we only consider point sources.

In our benchmark scenario there is no environmental regulation in place. We do, however, assume that all necessary legal and economic institutions are already in place; such as the environmental inspection agency, courts, senate…

Finally the marginal cost of public funds equals 1.2 (Mayeres, 1999) and the willingness to pay for an improvement in water quality equals € 31 per year for each ton of BOD removed (Rousseau and Proost, 2001b). We will provide a sensitivity analysis of this estimate.

2. Selection and specification of the regulatory chain

When we combine all possible instruments in the three stages we obtain thirty regulatory chains that could be of interest (Billiet et al., 2002). For each of these combinations we will consider several values for the instruments. By using different values for, for example, the emission tax rate we are able to construct a global welfare function defining the costs and benefits connected with a certain emission reduction.

[11] To obtain an internal solution it suffices to make the penalty additive instead of multiplicative.
[12] Biological Oxygen Demand (BOD) is after all the standard measure of pollution (Helland, 1998).

3. Monitoring and enforcement parameters

We assume that the fixed inspection probability $\overline{p}$ is equal to 0.1[13]. Next we assume that the variable inspection parameter a is equal to 0.5. The probability of inspection is therefore proportional to the size of the violation.

Finally we assume that the penalty parameter p is equal to 2. In Billiet (2001) we find that in Belgium the penalty for evading an emission tax is typically twice the evaded amount. Since we have no information on the other instruments, we use the same number for the penalty parameter.

In section IV we perform a sensitivity analysis on these parameters.

4. Abatement cost function

Explicitly modelling the firms' heterogeneity is important to capture the advantages of market-based versus command-and-control instruments. Therefore we made use of a firm level survey on abatement costs. We first contacted by mail 106 Flemish companies active in textile improvement and carpet production. Then we conducted a follow-up interview on site. We obtained useful cost estimates from 20 firms. We asked firms to state the costs of presently installed abatement technologies and of planned investment in the next two years. These data were used to estimate abatement cost functions for each company in order to represent firms' heterogeneity. In appendix A we give a summary of the cost estimates we obtained.

The cost estimates take both fixed and variable costs into account. We include initial investment costs, subsidies, personnel, energy and other costs. The life span of an investment is assumed to be 20 years. We assign all costs to only one pollutant, i.e. BOD, and therefore assume that the sole purpose of the investment is to reduce BOD emissions[14]. After calculating the net present value (NPV) of each technology we derive the associated annuities and use these in the model.

An extensive range of technologies was reported including filters, use of different inputs and wastewater treatment. Cost differences of abatement technologies between firms turn out to be large indeed; cost estimates (NPV) for one particular technology ranged from 1 million € in one firm to 4.7 million € in another firm.

5. Rule-making, implementation and enforcement costs

We identify fixed cost factors that result from the legal context and from the instrument itself (see Billiet et al., 2002). The cost factors resulting from the legal context are:

- guarantees required for civil rights;
- guarantees required for criminal pursuits;
- the possibility that an instrument is unavailable for a particular legislator;
- uncertainty about the competency status of an instrument or a variation thereof;

[13] This value is based on a press release from the Ministry of the Flemish Community on 11 June 2001. We read *'… that every class-I-firm is inspected thoroughly not even once every ten year'*. Since we only consider class-I-firms we can assume that every firm regardless of its compliance status has a ten percent probability of being inspected per year.

[14] In reality investments in abatement technologies often serve multiple purpose and reduce the output of several pollutants. This means that firms can 'overachieve' and do better than legally required. One way to deal with this overachievement problem can be found in Oates et al. (1989). In this paper, we make abstraction of this.

- dysfunctional structure of the instrument due to limitations in the division of competencies among government levels;
- structural susceptibility of the instruments for violations of the equality principle or the discrimination injunction

The cost factors resulting from the instrument itself are:

- administrative sustainability
- technical content (environmental and legal)
- knowability
- rules which require a procedure to be implemented
- legal formalisation
- time profile in the implementation stage
- rules which require an administration as implementation partner
- flexibility
- clustering

For each of these cost factors we have performed a relative valuation (see table 2) per instrument and per agent; and we haven taken into account the different stages of the regulatory chain. We include a wide variety of costs: the costs of lobbying, of filling in forms, of communicating with the administration, of performing inspections, of internal meetings, of legal counselling…

	Government			Households			Firms		
Instrument	RC	IC	EC	RC	IC	EC	RC	IC	EC
Emission standard	105	2+print	2.5	0.5		1	1	15 + lab	3.5
Authorising notification duty	35	0.5	0.5					1	
License system	137	35	3	0.5	0.5	0.5	2.5	26.5	1
Emission tax	133	6+print	5	0.5			1	20	8
Technology standard	75	2+print	2.5	0.25		0.5	1	8.5	1
Documentation duty	17	0.5	1.5					7	
Notification duty 1	15.5	0.5						0.25	
Notification duty 2	18.5+print	4.5+print	1.25					4.25	0.75
Testing duty	15.5								
Criminal fine	33	34			7.75			39	
Civil fine	62.5	65		0.25			0.25	13	
Transaction offer	63.5	2						1.25	

Table 2: Rule-making, implementation and enforcement costs (in man-days)

The enforcement, inspection and information costs were estimated using the same firm survey, by checking court rulings and by interviewing experts in the administration and in the law profession. The results are summarised in Table 2. An example of the cost breakdown for the emission tax can be found in appendix B.

The relative cost differences between the different instruments is what counts in this analysis. We do not want to stress the absolute values of these cost estimates. Therefore we have expressed the costs in man-days rather than in monetary terms. However, in order to calculate welfare effects we will need a monetary estimate of these costs. We have chosen an average gross wage level[15] in the textile industry of 37 €/hour. The average gross wage in the civil sector is assumed to be 50 €/hour. The value of time to the households is assumed to be on average 25 €/hour. The costs of analysing a sample in the lab are assumed to be € 372 on average. The costs of printing the regulatory information are assumed to be € 12395.

These costs are not used as such in the model. We have estimated and taken into account how often a particular instrument is used or changed by government, how often firms are punished for being in violation, etc. Costs associated with an emission tax are incurred each year and are, therefore, taken completely into account. Costs associated with an emission standard, on the contrary, are assumed to occur every four years and we, therefore, use the figure in table 2 divided by five (remember that we look at a time period of 20 years). Costs associated with inspections depend on the number of inspections performed.

IV. RESULTS

1. Base scenario

First we plot in Figure 1 the welfare effects and emission levels for one instrument combination, i.e. an emission tax combined with a documentation duty, a notification duty and a transaction offer. We consider the effect of implementing different tax rates.

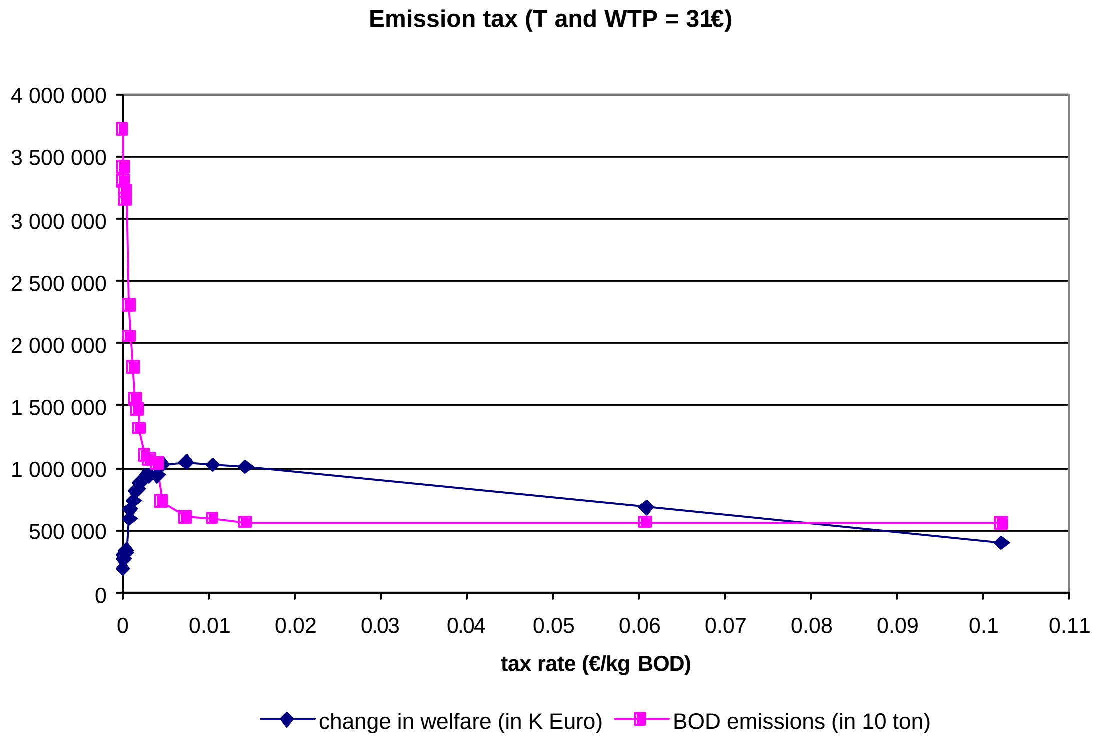

Figure 1

[15] This amount is based on the answers obtained when we questioned the textile firms.

BOD emissions reduce stepwise with an increasing tax rate because of the indivisibilities included via the abatement cost curves (see Figure 1). It is only profitable to invest in a particular abatement technology when the tax rate exceeds a certain level. The abatement cost function is therefore not continuous. Due to the same reason the welfare level changes stepwise. Once the tax rate exceeds a threshold value, the welfare level jump up only to slowly decline until another threshold is exceeded. This decline is caused by the increase in costs without a compensating decrease in emissions.

In order to provide some insight in the relative impact of the regulatory costs on social welfare, we give in Table 3 the rule-making, implementation (including abatement costs) and enforcement costs for the three different agents as a percentage of social welfare. It is clear from this table that the costs are substantial in absolute values but are less important relative to social welfare.

Instrument	Specification	Emissions (in ton BOD)	Social welfare (in K Euro)	Costs (RC+IC+EC+AC as % of SW)	
Emission tax	0.0025 €/kg BOD	13 138 316	872 205	Firm	2.03066
				Citizen	2.27372
				Government	0.03934
Emission standard	250 mg BOD/l	13 336 982	875 148	Firm	3.90443
				Citizen	1.35964
				Government	0.00923
Technology standard	WZI	13 883 376	824 558	Firm	10.57977
				Citizen	0.90191
				government	0.00667

Table 3

Completely in line with existing literature, costs for firms are highest with a technology standard and lowest with an emission standard. Costs for citizens are relatively high since many households are affected by the regulation. Differences between citizens' costs over the different instruments are due to our assumptions concerning the instruments' durability[16].

In the base scenario we exclude environmental benefits. A sensitivity analysis will check the influence of environmental benefits on the results. In Figure 2 we plot the welfare effect for all instruments combined with a transaction offer. In the figure we measure the emission level on the horizontal axis and the welfare level on the vertical axis. We immediately see that a certain amount of rest emissions (namely 5 563 192 ton BOD) will persist whatever firms or government do. This is due to our assumption that the industry's output remains fixed.

[16] We assume that emission taxes are adapted yearly while emission standards are only adapted every four years and technology standards every five years.

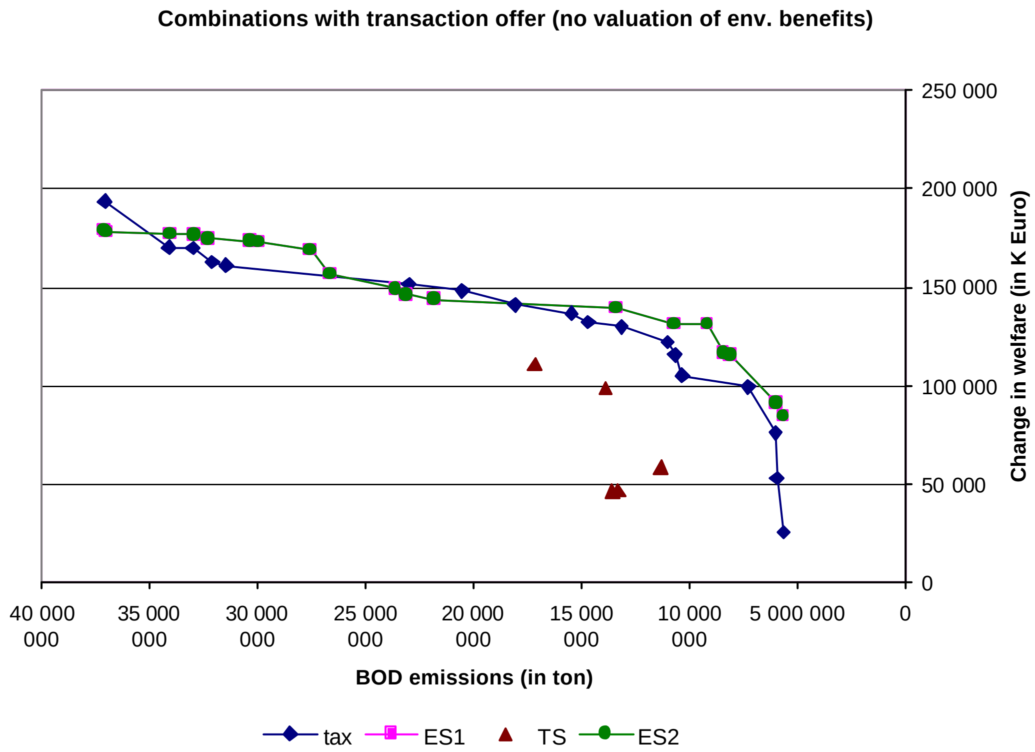

Figure 2[17]

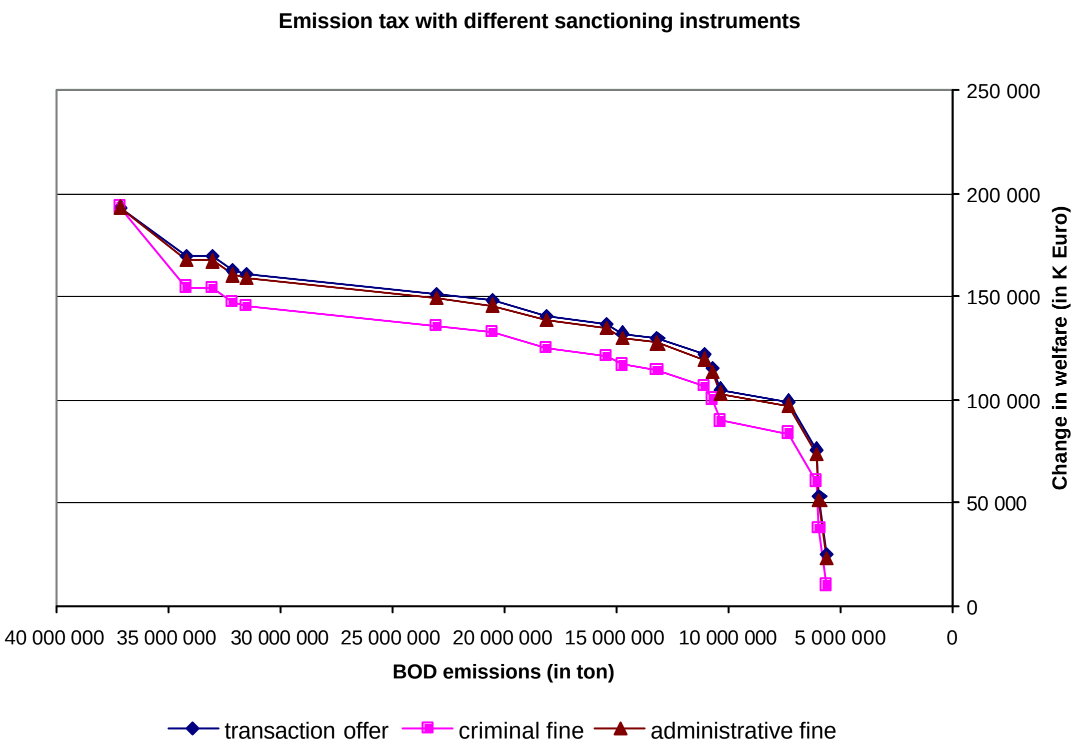

Figure 3

[17] Abbreviations are: emission tax *(Tax)*, emission standard version 1 or 2 *(ES 1/2)* and technology standard *(TS)*.

In Figure 3 we compare the different sanctioning instruments for an emission tax. The criminal fine is by far the most expensive instrument to use and, as could be expected, the transaction offer is the cheapest to use. However, in reality these three instruments are often used as complements. For minor violations or first time offenders, a transaction offer will often suffice. A criminal fine will be used for serious violations or extremely uncooperative firms. The administrative fine also has its specific use. Using an administrative fine avoids the social stigma associated with criminal fines. Therefore we cannot a priori choose one of the enforcement instruments as being *'the best'*. We need a dynamic model to study the power of this type of strategies more closely. An example of a model that punishes repeat offenders more severely is Harrington (1988).

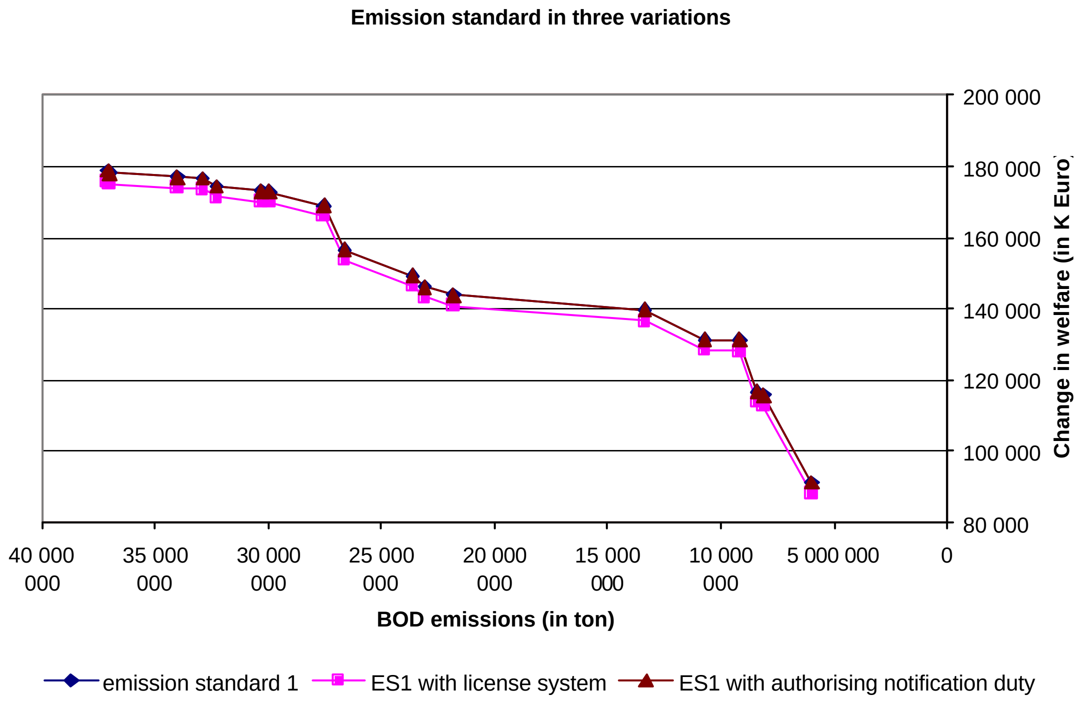

Figure 4

We compare three different versions of the emission standard in Figure 4. Adding an authorising notification duty to a standard only minimally increases the associated costs. Including the standard in a license system, on the contrary, markedly increases costs. We cannot say as such which formula the regulator should use since other criteria, besides costs, can play a role.

2. Sensitivity analysis

Sensitivity analysis shows that the results are – in certain aspects - highly sensitive to the differences in the willingness to pay (WTP) for water quality improvements. The higher the WTP for the improvement in environmental quality, the more it pays to pursue an environmental policy even if the emissions are only minimally reduced.

See for example Figure 5 for the welfare curves associated with three different level of WTP for the emission tax combined with a transaction offer. Remarkable is that the changes in WTP do not influence the relative position of the different instruments. This implies that the result of Oates et al. (1989) do not carry through in our model.

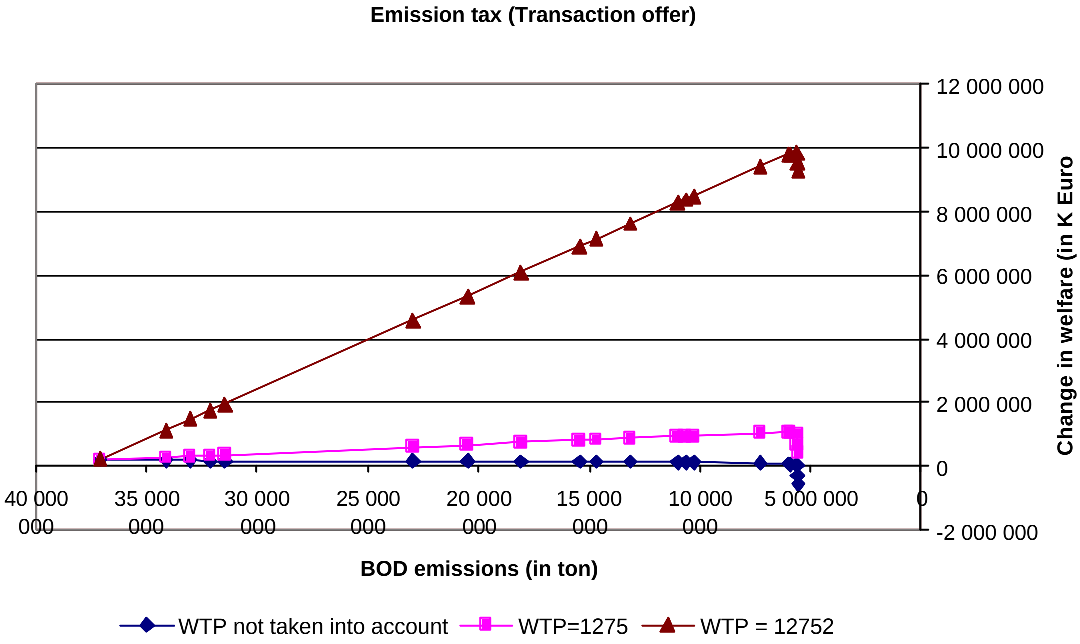

Figure 5

Sensitivity analysis with respect to the enforcement parameters (fixed inspection probability, coefficient of the variable inspection probability and the penalty coefficient) shows their immense importance. When the enforcement parameters are at a suboptimal level, it may be that is more cost effective not to have environmental regulation at all.

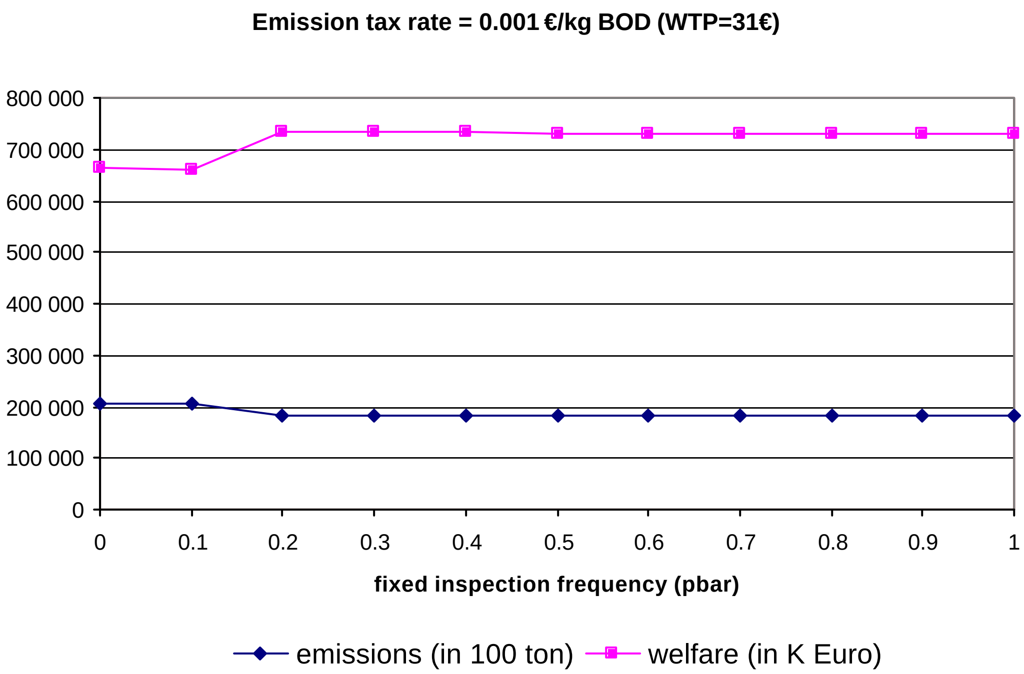

Figure 6

In Figure 6 we have plotted the change in welfare and emission reduction for one particular tax rate ($t = 0.001€/kg\ BOD$) when the fixed inspection frequency $\overline{p}_i$ changes from zero to one. An optimum is reached for a fixed inspection frequency equal to 0.2. The importance of correctly selecting this parameter is illustrated by this figure. Reducing the parameter from 20% to 10% decreases welfare with approximately 74 million Euros.

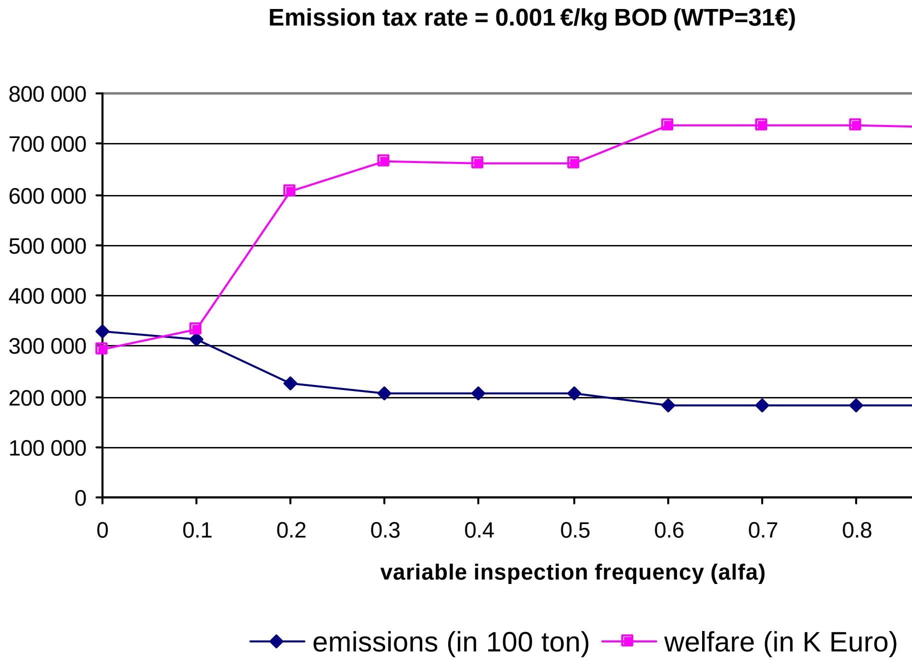

Figure 7

In Figure 7 we perform the same exercise for the variable inspection parameter α. Again an optimum can be reached, namely for α equal to 0.6. Tests have shown us that both inspection parameters (fixed inspection frequency and variable inspection parameter) influence each other. In order to optimise the inspection policy, government will have to fix both parameters simultaneously. This surely is an exercise worth doing since welfare can increase considerably.

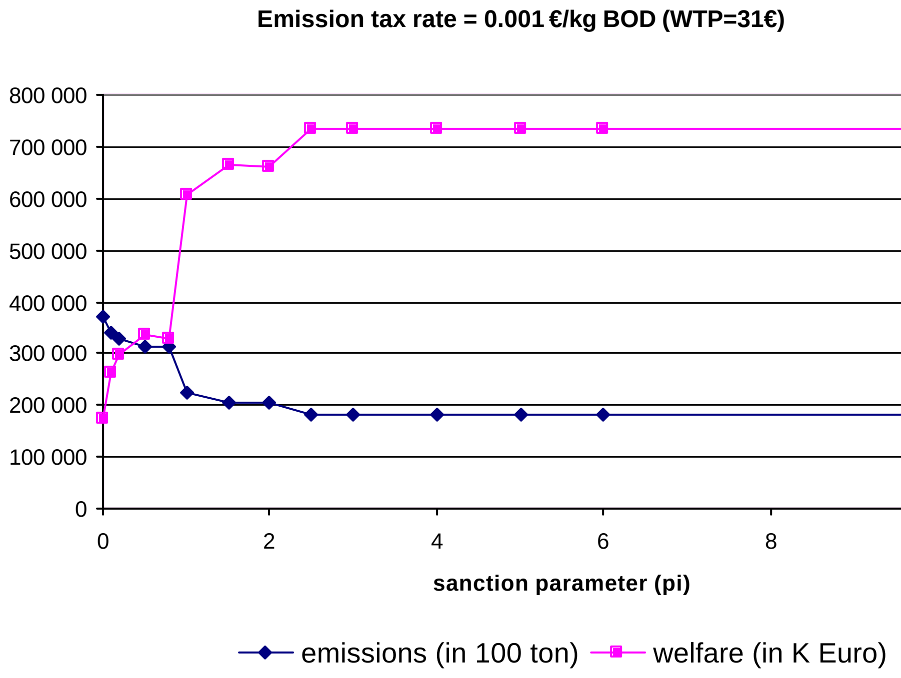

Figure 8

Finally we perform the same exercise for the penalty parameter π[18]. One immediately sees that the penalty greatly influences the outcome: resulting emissions range from 37,1 million to 18,1 million ton BOD. Welfare levels range form 175 million to 735 million Euros. The penalty can be used as substitute for a higher tax up to a certain point. Manipulating the penalty cannot achieve the same emission reduction as manipulating the tax rate beyond the limit of 18.1 million ton BOD for this specification.

V. CONCLUSION

The global welfare functions associated with each regulatory chain lead us to six key observations.

1. First, in order to obtain a given emission reduction, the technology standard turns out to be the most expensive instrument. Moreover, the use of this instrument is extremely limited since it can only reach as many levels of emission reductions as there are abatement technologies and the obtained result is highly sensitive to changes in the monitoring and enforcement parameters.
2. Identifying the instrument that leads to the highest welfare level was less clear-cut. The welfare curves for emission standard and emission tax cross each other several times. We can nevertheless say that an emission standard is less costly than an emission tax for most of the emission reduction levels. These results are also sensitive to changes in the monitoring and enforcement parameters and to the emission tax procedure used in Belgian environmental law.
3. Further we compared three different versions of the emission and technology standard. Adding an authorising notification duty to a standard only minimally increases the associated costs. Including the standard in a license system, on the contrary, markedly increases costs.
4. The criminal fine is by far the most expensive sanctioning instrument to use and, as could be expected, the transaction offer is the cheapest to use. However, in reality these three instruments are often used as complements. For minor violations or first time offenders, a transaction offer will often suffice. A criminal fine will be used for serious violations or extremely uncooperative firms. The administrative fine also has its specific use. Therefore we cannot a priori choose one of the enforcement instruments as being *'the best'*.
5. Sensitivity analysis shows that the results are – in certain aspects - highly sensitive to the differences in the willingness to pay (WTP) for water quality improvements. The higher the WTP for the improvement in environmental quality, the more it pays to pursue an environmental policy even if emissions are only minimally reduced. Remarkably the changes in WTP do not influence the relative position of the different instruments.
6. Sensitivity analysis with respect to the enforcement parameters (fixed inspection probability, coefficient of the variable inspection probability and the penalty coefficient) shows their immense importance. Choosing the optimal level of the parameters is crucial to the decision of the appropriateness of environmental regulation. Changing the level of the parameters can suddenly make a policy worthwhile pursuing.

In conclusion we can say that adding a detailed identification and estimation of information, monitoring and enforcement costs linked to an environmental policy, can greatly change traditional results with respect to the relative efficiency of instruments. Our numerical illustration proves this

[18] We assume that every penalty parameter p_{es}, p_{et}, p_{ts} is equal to 2. For short we refer to the penalty parameter as π in the rest of the text.

point by showing how an emission tax can be the most expensive instrument to use in order to obtain a particular level of environmental quality. This result holds even if we include heterogeneity of the industry into our model.

Moreover we have also shown that it is important to use a correct estimate of the willingness to pay for environmental quality improvements but that it is even more important to formulate an appropriate monitoring and enforcement policy. The decision of whether to pursue an environmental policy or not depends on it.

APPENDIX A – Abatement cost estimates

To guarantee anonymity of the participating firms we did not explicitly name technologies and firms.

Firm	Technology	NPV (in €)	BOD	COD[19]	Other chemicals	Water
A	T1	3 168 402		X	caprolactam	
	T2	354 113				
B	T1	1 051 470	X	X		
	T3	24 789			Latex	
	T4	12 394 676				X
	T5	9 916				X
C	T6	191 326				X
D	T7	1 859 201	X	X	N, Zn, Ni, Cr	
	T8	371 840		X	metals, salts, colour	
	T9	421 419		X	metals, salts, colour	
E	T10	49 579				X
	T5	718 891				
	T11	463 395	(X)[20]	(X)		
F	T13	1 983				X
	T12	-111 159	(X)	(X)	Latex	
H	T13	2 220				X
	T14	20 035				
	T15	103 650	X	X		
	T12	133 570	X	X		
	T16	10 018				X
	T17	80 142	(X)	(X)		
	T18	66 785				X
I	T23	339 823			SS	
J	T24	294 459				X
	T13	5 404				X
	T18	49579				X
	T25	3 470 509				X
	T26	1 611 308				X
	T12	594 944	X	X		
	T19	1 363 414	(X)	(X)	(Metals, SS)	

[19] Chemical oxygen demand
[20] (.) = estimate, not based on data obtained from that firm but analogue to other companies

K	T1 T12	4 719 663 *<u>495 787</u>*[21]	X (X)	X (X)	N, Ni	
L	T1 T21	1 090 393 347 051	X (X)	X (X)	SS	
M	T3 T20 T27 T11 T28	358 869 9 916 -21 625 *<u>495 787</u>* 19 794	X X 	X X 	SS, Zn SS, Zn SS, Zn 	 X
N	T13 T19 T12	4 958 371 840 88 081	 (X) (X)	 (X) (X)	 (Metals, SS) 	X
O	T29 T3 T22 T13 T23	123 947 1 050 737 366 512 992 149 000			Fibres Fibres, latex Inputs Inputs	 X X X
P	T1 T18 T30	2 133 371 47 959 495 787	X 	X 	SS, N, F, Metals 	 X X
R	T3	1 687 658		X	Zn, Mangaan	
S	T31	12 870			latex	X
T	T32 T33	-75 618 199 346	(X) 	(X) 		
U	T11 T19 T16	37 184 1 041 153 195 787	(X) X 	X X 	 (Metals, SS) 	 X
V	T34	71 702				

APPENDIX B - Rule-making, implementation and enforcement costs associated with an emission tax.

Emission tax[22]	Firm			Households			Government		
	RC	IC	EC	RC	IC	EC	RC	IC	EC
Technicity	1d partici-pation	8d info realisation, technology	2d contra analysis	1/2d partici-pation			12d state of the art		
Knowability			1d proof						1d[23] control samples
Procedure		3d administration	4d[24] appeal				1d procedure	3d adminis-tration	4d appeal

[21] ___ = estimate of costs analogue to other companies
[22] The declaration of the tax is not taken into account. It is captured in the notification duty.
[23] Control and enforcement are difficult to implement since one has to work backward in time (for the past year).

Juridical Formalisation							XXL[25]		
Time profile		5d Self-control	1d accompanying, certified expert					2d inning	
Administrative Partner									
Flexibility		4d info, negotiation, strategy						1d negotiation	

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[24] We assume that firms go into appeal once every three years and that this takes them 12 days per appeal.
[25] Less in volume than license system but needs the Flemish parliament more often.

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